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ORIGINAL RESEARCH

A PILOT STUDY OF CORE STABILITY AND ATHLETIC PERFORMANCE: IS THERE A RELATIONSHIP?

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ABSTRACT

Study Design: Correlation study

Objectives: To objectively evaluate the relationship between core stability and athletic performance measures in male and female collegiate athletes.

Background: The relationship between core stability and athletic performance has yet to be quantified in the available literature. The current literature does not demonstrate whether or not core strength relates to functional performance. Questions remain regarding the most important components of core stability, the role of sport specificity, and the measurement of core stability in relation to athletic performance.

Methods: A sample of 35 volunteer student athletes from Asbury College (NAIA Division II) provided informed consent. Participants performed a series of five tests: double leg lowering (core stability test), the forty yard dash, the T-test, vertical jump, and a medicine ball throw. Participants performed three trials of each test in a randomized order.

Results: Correlations between the core stability test and each of the other four performance tests were determined using a General Linear Model. Medicine ball throw negatively correlated to the core stability test ($r -0.389$, $p = 0.023$). Participants that performed better on the core stability test had a stronger negative correlation to the medicine ball throw ($r = -0.527$). Gender was the most strongly correlated variable to core strength, males with a mean measurement of double leg lowering of 47.43 degrees compared to females having a mean of 54.75 degrees.

Conclusions: There appears to be a link between a core stability test and athletic performance tests; however, more research is needed to provide a definitive answer on the nature of this relationship. Ideally, specific performance tests will be able to better define and to examine relationships to core stability. Future studies should also seek to determine if there are specific sub-categories of core stability which are most important to allow for optimal training and performance for individual sports.

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INTRODUCTION

Core training has become the norm in many athletic training programs throughout the United States during the past decade. Equipment such as the therapy ball, BOSU™ ball (Fitness Quest, Canton, Ohio), and the abdominal roller have been described as quick and easy fitness solutions for our exercise deprived society. The mantra of "core training" makes athletes believe that enhanced core stability will improve their performance on the field or court. Although the media portrays these ideas as truth, the scientific community remains uncertain as to the relationship between core stability and athletic performance. This relationship may prove challenging to define because functional and core demands are typically sport or position specific and many questions, such as which element of core stability is most essential to performance, remain unanswered. The purpose of this pilot study is to analyze the relationship between a test of core stability and athletic performance measures.

The current literature offers a variety of suggestions for defining core stability, but remains unclear on a precise conclusion. According to Tse et al,[1] "The core musculature includes muscles of the trunk and pelvis that are responsible for maintaining the stability of the spine and pelvis and are critical for the transfer of energy from larger torso to smaller extremities during many sports activities." Therefore, it is theoretically believed that if the extremities are strong and the core is weak the decrease in muscular summation through the core will result in less force production and inefficient movement patterns. Kibler et al[2] defines core stability as "the ability to control the position and motion of the trunk over the pelvis to allow optimum production, transfer, and control of force and motion to the terminal segment in integrated athletic activities." Panjabi[3] stated that core stability is achieved by the integration of the active spinal stabilizers (muscles), passive stabilizers (spinal column), and neural control which act together to control intervertebral joint range of motion in order to allow for the performance of activities of daily living. Thus, the definition of core stability may depend strongly on the context in which it is applied. Hibbs et al[4] propose that elite level athletes require much higher levels of core stability for sport performance than during activities of daily living, therefore they must have appropriate rehabilitation to enhance return to function. These definitions suggest that core stability in athletics involves dynamically controlling and transferring large forces from the upper and lower extremities through the core in order to maximize performance and promote efficient biomechanics.

Many different models of the core anatomy have been proposed in the literature that attempt to explain the complex interaction between the muscular and neural elements. These models often differ depending on the context in which they were developed. Some researchers have described the core as a double walled cylinder with the diaphragm as the roof, abdominals as the front, paraspinals and gluteals as the back, and the pelvic floor and hip musculature as the bottom.[5] Researchers with a specific interest in sports suggest that the core includes all the musculature between the sternum and knees, with a specific focus on the low back, hips, and abdominals.[6] It has also been suggested that the core should include the muscles of the shoulder and pelvis because they are critical in the transfer of forces across the body.[7]

Bergmark[8] explained the function of the core musculature by dividing the trunk muscles into local and global categories. Local muscles are defined as those attaching to the lumbar vertebrae and influencing inter-segmental motion, while global muscles attach to the hips and pelvis and promote mobility and proper orientation of the spine. Bergmark stated that maintaining balance in these muscles is important because if the local muscles are not functioning properly, movements become inefficient due to compensation of the global muscles thus altering stability.

Nichols[9] expanded on Bergmark's work by dividing the core musculature into muscles that operate by length dependent and force dependent activation patterns. He elaborated that the muscles operating on length dependent patterns are small, short muscles with small lever arms that typically span one joint. The force dependent muscles cover multiple spinal segments, produce higher levels of force, and coordinate multiple joints. Accordingly, it is the combination of both muscle activation patterns that allows for control of the multi-segmented spine and the neutralizing of forces.

In order to completely understand the concept of core stability, it is essential to be aware of the role that each muscle plays in the overall scheme of coordinated movement. The abdominal muscles, consisting of the transversus abdominis, rectus abdominis, and internal and external obliques, are primarily involved in controlling the position of the spine and pelvis. The transversus abdominis increases intra-abdominal pressure and tensions the thoracolumbar fascia while the abdominals collectively contract to create a rigid cylinder to stabilize the spine.[10,11] It is the thoracolumbar fascia that connects the upper and lower extremities in order to integrate the superior/inferior and right/left parts of the kinetic chain. The thoracolumbar fascia is also connected to the internal obliques and transversus abdominis and functions to provide further cylindrical stabilization to the spine.[12] The diaphragm also has been shown to assist with spinal stability by contracting prior to limb movement and independent of respiration.[13]

The hip and pelvic floor musculature serves as the base of support for the core. According to Hodges[14], synergistic activation patterns exist in pelvic and trunk controlling musculature. The hip musculature, with its large cross-sectional area, is involved with stabilization of the trunk as well as force and power generation during lower extremity movements in sports activities. The gluteal muscles stabilize the trunk over a planted leg in order to supply power for forward leg motions in movements such as throwing and running.[15,16] For efficient and skillful movement to occur, the collective musculature of the core must be activated in precise patterns to both generate and absorb force while stabilizing the trunk.

To maintain stability of the core, the body must integrate sensory, motor-processing, and biomechanical strategies coupled with learned responses and the ability to anticipate change.[17] Thus, the body must control the trunk in response to internal and external perturbations, which include forces generated by the distal extremities as well as expected/unexpected challenges to stability.[18] Anticipatory postural adjustments of the core are determined by pre-programmed muscle activations.[2] Ebenbichler et al[13] demonstrated this concept in showing that other muscles contract before the limb agonist when stability is challenged due to limb movement. These postural adjustments allow the body to increase proximal stability and allow distal mobility. Additional studies which have analyzed the response of the superficial muscles in response to external perturbations have revealed a direction-specific activation pattern in order to maintain proper orientation of the spine.[19,20] Some studies on the function of the transversus abdominis have revealed an activation pattern that is independent of the direction of externally applied force while more current studies have reported that feed forward activity of the muscle is not bilaterally symmetrical and is specific to the direction of arm movement.[11,21]

The importance of the neuromuscular system, as it pertains to the core, has been clarified through research specifically addressing muscle activation patterns during sports activities. It has been demonstrated that, in response to rapid arm movements, muscle activation patterns begin in the lower extremity and proceed upwards through the trunk and to the arm.[22] This pattern of force development from the ground through the core to the extremity has been shown in tennis[16], baseball[23], and kicking activities.[15] Cook[24] described the concept of alternating patterns of joint stability and mobility throughout the body that serves to enable functional activities and that loss of stability at one joint requires provision of stability at the adjoining segments. Researchers have demonstrated a similar analysis in pitching as there is a consistent pattern of muscle activation that begins with the contra-lateral external oblique and proceeds to the arm.[23] The importance of core stability is further evidenced by findings that suggest the trunk and peri-scapular muscles are responsible for nearly 85% of the muscle activation required to decelerate the forward moving arm during throwing.[25] These findings provide a basis for further research to evaluate the specific role of core stability in performance, injury, and rehabilitation.

The relationship between core stability and injury prevention is also relevant. A study by Zazulak et al[26] evaluated trunk displacement and stiffness in response to movement, as well as the ability to determine spatial position of the trunk. Results of the study indicated that factors related to core stability predicted knee injury with high levels of sensitivity and moderate specificity in female but not male athletes. An interesting study performed by Leetun et al[27] compared core stability between genders and between athletes who reported an injury during their season versus those who did not. Athletes who did not sustain an injury were significantly stronger in hip abduction and external rotation with external rotation being the only significant predictor of injury status. The authors concluded that core stability has an important role in injury prevention and may be used to assess injury risk. If a relationship does exist between core stability and sports performance, athletes possessing higher levels of core stability also may be less susceptible to injury. Evidence of this combined relationship would have major implications in clinical practice and sports specific training.

Over the past several years, the body of literature concerning the relationship between core stability and athletic performance has significantly increased. However, this relationship has still not been defined, and relatively few studies have attempted to quantify a correlation between the two variables. A similar study to the current investigation was conducted by Nesser et al[28] which evaluated the relationship between isometric endurance core exercises and performance measures in Division I college football players. The authors reported weak to moderate correlations between measures, with inconsistent results. It was noted by the researchers that the tests used to evaluate the core focused more on endurance rather than strength and that the latter may be more critical to athletic performance. Abt et al[29] studied the relationship between core stability and cycling mechanics of the lower extremity. The results indicated that core fatigue resulted in altered cycling mechanics that may possibly place the lower extremity at risk for injury due to increased forces at the knee. However, no significant differences were observed in pedaling forces. Because fatigue affected lower extremity alignment and mechanics, the authors suggested that core stability and endurance may improve both these measures. To the knowledge of the current authors, these are the only studies that have specifically focused on quantifying the relationship between core stability and athletic performance, leaving a variety of questions unaddressed.

A greater number of researchers have evaluated the effects of core training on sports performance. Tse et al[1] analyzed the effectiveness of an 8 week core endurance exercise protocol on college aged male rowers. At the conclusion of the study, the authors reported that although their program did improve core endurance, but did not improve functional performance in tests such as the vertical jump, broad jump, shuttle run, and 40 m sprint. This led the researchers to state that core strength and power may be more influential in functional performance. Stanton et al[30] studied the effects of short term therapy ball training on core stability and running economy. It was found that the therapy ball training resulted in improvement of what they defined as core stability, but had no effect on physical performance measures. Scibek et al[31] noted similar results in a study that investigated the effects therapy ball training on swimming performance. It was noted that therapy ball training improved core stability measurements, but did not transfer to improved swim performance. Sato and Mokha[32] studied the effects of a 6 week core stabilization training program on ground reaction forces, stability of the lower extremity, and overall running performance in recreational and competitive runners. Their results indicated a significant improvement in 5000 meter running times with no changes in ground reaction forces or leg stability. Multiple interventions related to the design of the study, precludes the conclusion that core stability training specifically improved running performance. It can be summarized from the studies discussed above that although core training has been shown to improve core stability; the results have not translated into performance enhancement.

The aim of this research was to investigate the relationship between core stability, measured by the double leg lowering test (DLL), and athletic performance tests in college athletes. Currently, the literature does not identify a single test or battery of tests which are considered to the most effective for evaluating core stability. However, based on the available evidence the authors have concluded that the DLL test is an appropriate way to measure core stability as it pertains to athletic function. The DLL test has been shown to require significant levels of muscle activation[33] and required a high level of intrinsic trunk stabilization due to the long lever arm of the legs and a narrow base of support for the trunk and upper extremities. Lanning et al[34] gave further support for the use of the DLL test, which focuses on core stability during lower extremity motion, noting that athletic skills require coordinated and synchronized contractions of the abdominals and lower extremity musculature simultaneously. Krause et al[35] reported that in healthy subjects the DLL test has excellent intra-tester reliability, thus providing further evidence for the use of the test in the current study.

The objective of this study was to critically evaluate the relationship between a core stability test and athletic performance measures. Several studies have examined the impact of core muscle training on performance outcomes with minimal success and few conclusions. It appears that the focus of research in this area may need to first be directed to research to determine whether tests of core stability are related to athletic performance measures. The gathered data was analyzed to elucidate this relationship as it pertains to male and female athletes in a variety of sports. It is possible that performance in specific sports is highly correlated to specific measures of athletic performance, while other sports demonstrate no relationship. Therefore, to achieve excellent performance in certain sports may require varied levels of core stability. Findings such as these would greatly impact the sports performance and rehabilitation literature because it would serve as the basis for sport specific exercise prescription and help with identifying appropriate training for higher level athletes. If this relationship can be described using objective and valid measures, further research can focus on sport specific core stabilization training programs based on the specific functional demands of varied sports or activities in order to enhance rehabilitation efforts.

MATERIALS AND METHODS

Thirty-five volunteer subjects were tested at Asbury College Luce Physical Activities Center. The subjects were all student athletes from Asbury College (NAIA Division II). The athletic teams represented in the current study population included; men's basketball (2), women's basketball (8), men's soccer (7), women's tennis (1), women's volleyball (7), and men's/women's swimming (4 female/6 male). Average age was 19.25 years with a range of 18–22. Subjects were excluded if they had experienced a musculoskeletal and/or abdominal injury which required them to seek treatment in the past 60 days. All participants performed 10–15 minutes of warm-up activities before participating in any of the athletic testing stations. The athletes reported to the testing site in groups related to their team membership and completed the test sequence as a team. Activities were completed by 34 of the 35 subjects (97%). One male soccer player dropped out after experiencing foot pain, portions of his data were recorded and used for analyses.

The subjects were given a scoring sheet before testing in order to allow the researchers to record their performance at each athletic testing station. The scoring sheets had the starting position and rotation sequence for the athletic testing sequence in the upper left corner. The sheets had 1 of the 5 possible sequences and were distributed randomly to the subjects as they came in the door. The five testing stations included abdominal leg lowering test, vertical jump, 40-yard dash, T-test, and a medicine ball throw. The vertical jump, 40-yard dash, T-test, and medicine ball throw are not direct measures of sport performance, but they do measure factors or components of many sports. The factors of power, speed, and agility are three components in most sporting events. During the current study, the examiner at each station explained the testing procedure and the proper technique to perform the test. Following instruction subjects were given a practice trial at each testing station in order to allow the subject to acclimate to and understand how to perform the test and allow for the best performance possible. The subjects were instructed not to perform at maximum exertion during the practice trial. The subjects were given the opportunity to ask questions of the examiner at the station for further explanation about the test. The examiner gave no other feedback except to correct improper technique as outlined by the researchers in the instruction. The subject was given a 4 minute rest period following the practice trial before the first recorded performance. During the recorded performance subjects were not given encouragement or feedback from the examiner except to correct any improper technique as outlined by the researchers in the instruction. Once the subject completed the performance at the first testing station he/she rotated to the next testing station on his/her list. Each subject was given a minimum of a 4 minute break between each testing station in order to allow

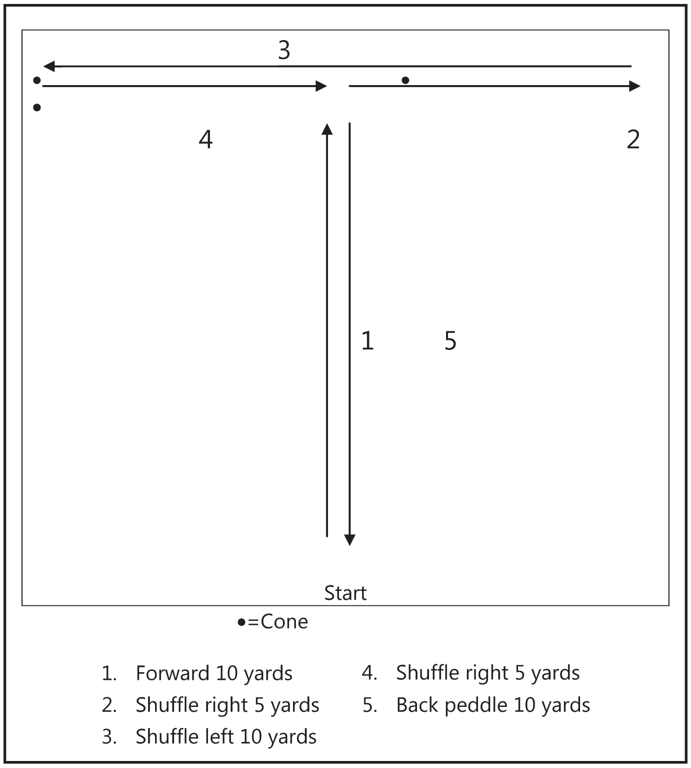

Figure 1. *T-test (Agility Run)*

for adequate recovery. He/she completed all 5 athletic testing stations before restarting the sequence. The subjects completed each testing procedure 3 times.

The T-test is a measure of leg power, speed, and agility.[36] (Figure 1) In order to produce what is perceived as a quality performance or good time in the T-test an athlete must have explosive power during direction changes, speed to cover the course, and agility to maneuver the course.[36] The examiner at the T-test instructed the subjects to sprint to a cone 10 yards straight ahead. The subjects sprinted on the left side of the cone that was ten yards in front of them. From there, the subjects shuffled 5 yards to the right and touched a cone with his/her hand. Next, the subjects were instructed to shuffle 10 yards to the left (passing the center cone) and touch a cone with his/her hand. The subject was instructed to shuffle 5 yards back to the right to the center cone. The test was completed with a 10 yard backpedal across the finish line. Following instruction the subject was given the opportunity to practice the test. The participant began the test at his or her discretion and timing began with the first movement observed. Once the participant crossed the finish line during the back pedal sequence, the test was terminated. The participants were monitored during the test to ensure all sequences were completed successfully without knocking over cones. The athletes were not allowed to cross their feet with the side shuffle. If a sequence was performed incorrectly, the test was terminated and the participant repeated the test after a 4 minute break. Timing was determined using a digital stopwatch. If the procedure was performed correctly the examiner recorded the score to the nearest one hundredth of a second.

The 40 yard dash is a measure of power and speed.[37,38] The athlete needs power to initiate movement and accelerate quickly to top speed.[47] The athlete needs speed in order to cover the course as quickly as possible. The 40-yard dash consisted of a 40 yard linear course marked by cones. The subjects were instructed to run his/her hardest from point A to point B. Each subject was given one practice trial if he/she desired. The subject began the test at his or her discretion and timing began with the first observed movement coming out of a sprinting starting position. Once the participant crossed the finish line the test was terminated. If the subject tripped or stumbled at any point during the 40 yards, the test was terminated and the subject took a 4 minute break before repeating the test station. Timing was recorded via a digital stopwatch. If the procedure was performed correctly the examiner recorded the score to the nearest hundredth of a second.

The medicine ball throw is a measure of power.[39] Many athletes need explosive power in his/her upper extremities in order to throw the ball or propel an object.[39] The examiner used a marked line on the floor as the starting reference for this testing station. A padded mat was placed on the floor and the front of the mat was aligned with a reference line. Before the testing procedures began the examiner taped a measuring tape on the ground out to 50 feet. The examiner instructed the subject to tall kneel (90 degrees of knee flexion and neutral trunk position) on the front of the mat with the medicine ball held at his/her chest level against the chest wall. The male subjects used a 6.6 pound medicine ball and the female subjects used a 4.2 pound medicine ball as recommended by Stockbrugger.[39] From this position the subject was instructed to throw the medicine ball, using a 2 handed chest pass technique, as far as they could. The subject was instructed not to "rock back" or "pump" the ball before initiating the throw to minimize momentum and muscle substitution. The subject was allowed to come forward after the throw but was not allowed to catch himself/herself with his/her hands. If the subject performed the procedure improperly no score was given, the technique was corrected, and he/she took a 4 minute break before repeating the testing station. The subject was given a practice trial before initiating the recorded performance. The subject was instructed to throw the ball as far as they could next to the tape measure. The examiner marked the first contact site with the floor and used the tape measure to determine the distance. If the procedure was performed correctly, the examiner recorded the score to the nearest inch.

The vertical jump is also an assessment of power.[38] Many athletes need explosive lower extremity power in order to get off the ground and reach a maximum jump height.[38] The examiner used a Vertec (Vertical Jump Tester – Sports Imports, Columbus, Ohio) to measure the vertical jump of the subjects. The examiner first measured each subject's reach with the Vertec Vertical Jump Tester and adjusted the height of the device as necessary. The examiner instructed the subjects to jump off both feet with no step into the movement. The subjects were allowed to squat, but no movement of the feet was allowed prior to the jump itself. The arms were allowed to swing as desired by the athlete. The subject was instructed to jump as high as he/she possibly could and deflect as many of the measurement bars on the device as possible. After instructions subjects were given one practice trial to perform the technique. If the subject performed the procedure improperly no score was given, the technique was corrected, and the subject was given a 4 minute rest before retesting. If the procedure was performed correctly the examiner recorded the score to the nearest one half -inch.

The final testing station was the double leg lowering station measuring abdominal strength, which served as the test of core stability.[33,34] The examiner positioned a flat table in the corner of the room. A large goniometer was drawn on a poster board and taped on the wall next to the table.[34] The subject was positioned on the table in supine with their greater trochanter approximating the axis point of the goniometer.[34] The examiner first taught the subject how to move the pelvis into a posterior pelvic tilt. In this position the low back is flattened against the bed. The examiner did not initiate testing until the subject could perform a posterior pelvic tilt adequately. The examiner instructed the patient to keep his/her back flat against the bed and maintain the posterior tilt of the pelvis as he/she lowered their legs from 90 degrees of hip flexion.[34] The subject was given one practice trial without the stabilizer in place. Following the practice trial the examiner placed a Stabilizer (Chattanooga Corporation, Hixson, Tennessee) underneath the subject's low back. The Stabilizer in this study was a small blood pressure cuff like device. The bladder was filled with air using a hand pump and there was a dial to read the amount of pressure in the bladder. The patient was instructed to perform a posterior pelvic tilt with the stabilizer under his/her low back. The examiner pumped the stabilizer bladder to 40 pounds of pressure. The subject was instructed and verbally cued to maintain the 40 pounds of pressure throughout the test. The examiner passively lifted the subject's legs to 90 degrees of hip flexion with bilateral knee extension.[34] The subject actively slowly lowered his/her legs while maintaining a posterior pelvic tilt and the 40 pounds of pressure in the bladder. If the subject was unable to maintain the posterior pelvic tilt, his/her low back came off the table and the pressure would drop in the bladder. When the examiner saw the pressure drop below 40 pounds of pressure (and was unable to regain pressure when urged) he stopped the movement by putting his arms under the patient's legs. The examiner would measure the angle of the thighs using the wall goniometer as described by Lanning et al.[34] The score was recorded to the nearest degree. If the subject performed the technique incorrectly no score was recorded and the subject repeated the test following a 4 minute rest break.

STATISTICAL ANALYSIS

Descriptive statistics were used along with correlation tests in order to determine whether relationships existed between core stability (double leg lowering) and performance on the performance tests (T-test, 40-yard dash, Vertical Jump, Medicine Ball throw). These values were examined between males and females separately, athletes of each sport, and the top and bottom performers on the core strength test. The best score that each participant obtained on each of the performance tests was used for correlation analysis with the best score that the participant achieved in the double leg lowering test, using the Pearson Correlation Coefficient. The population was halved using the median score for core stability. The same correlations as above were taken to determine if there was a difference in performance for those with greater core stability. To determine whether statistically significant relationships existed, the p value was determined a priori at $p < .05$.

ANOVA was used to determine which variables had the greatest influence on the results of each test. Variables, both continuous and discrete, included: age, gender, sport, and the order of testing. Data were analyzed using SPSS software.

RESULTS

Descriptive results for males and females on all performance tests are presented in Tables 1 and 2. The mean degree achieved during the double leg lowering test for females was 54.75 degrees, and 47.43 degrees for males. The lower mean value in this test represents a better score. Recall that this test was selected as a measurement of core strength. Correlational data results showed weak, non-significant correlations between abdominal strength and the T-test ($r = 0.052$), forty-yard dash ($r = 0.138$), and the vertical jump ($r = -0.172$). A negative correlation was discovered between abdominal strength and the medicine ball throw (–0.389), however, this correlation may only be considered a weak or low correlation (0.2–0.4 range seen) as most general statistical descriptors of relationship require greater than 0.5 to begin the moderate to strong rankings. The medicine ball throw was the only significant relationship to core strength with a p-value of 0.023. Results can be seen in Table 3.

Table 1. *Correlation between leg lowering and performance tests, all participants (n = 35)*

Performance Test (Best Score)	Pearson Correlation (r)	p Values
T-Test	0.052	0.768
Forty Yard Dash	0.138	0.438
Vertical Jump	-0.172	0.331
Medicine Ball Throw	-0.389	0.023*
*Statistically significant		

Table 2. *Correlation between leg lowering and performance tests, males only (n = 15)*

Performance Test (Best Score)	Pearson Correlation (r)	p Values
T-Test	-0.148	0.614
Forty Yard Dash	-0.148	0.833
Vertical Jump	-0.179	0.540
Medicine Ball Throw	-0.322	0.026*
*Statistically significant		

Table 3. *Correlation between leg lowering and performance tests, females only (n = 20)*

Event (Best Score)	Pearson Correlation (r)	p Values
T-Test	-0.144	0.544
Forty Yard Dash	-0.174	0.463
Vertical Jump	0.217	0.358
Medicine Ball Throw	-0.268	0.025*
*Statistically significant		

When the results were divided into male and female categories, the medicine ball throw was still the test that was most strongly correlated to core strength. Male and female data were found to have statistically significant weak correlations (0.2–0.4). See Tables 2 and 3 for data.

To determine if there was a difference in correlation between test values in those who had higher core strength scores and those who had lower core strength scores, the data were halved. The median core strength score was used to divide the participants. Both top and bottom performers showed the strongest and most significant correlation between the medicine ball throw and core strength. The top performers showed a much stronger correlation and significance than the bottom performers. No correlations for the bottom performers were found to be statistically significant. See Tables 4 and 5. Although a General Linear Model through ANOVA was applied (Table 6), a strong relationship to individual variables was not identified.

Table 4. *Correlation between leg lowering and performance tests, top performers (n = 18)*

Event (Best Score)	Pearson Correlation (r)	p Values
T-Test	0.170	0.500
Forty Yard Dash	0.280	0.261
Vertical Jump	-0.246	0.326
Medicine Ball Throw	-0.527	0.025*
*Statistically significant		

Table 5. *Correlation between leg lowering and performance tests, bottom performers (n = 17)*

Event (Best Score)	Pearson Correlation (r)	p Values
T-Test	0.314	0.236
Forty Yard Dash	-0.190	0.481
Vertical Jump	-0.009	0.974
Medicine Ball Throw	-0.352	0.181
*Statistically significant		

DISCUSSION

In theory, it is accepted that core stability and athletic performance are interrelated; however, the current literature does not support this relationship. The purpose of this study was to examine the relationship between a core stability test and tests of performance using the double-leg lowering test as a measure of core strength/stability in male and female collegiate athletes in a variety of sports. The strongest correlation between DLL and functional measures was found with the medicine ball throw, which is a test of muscular power. When the double-leg lowering scores were halved to separate into top and bottom performers, a significant relationship was discovered between the top half of performers and the medicine ball throw compared to the bottom performers. Those perceived as better performers did have a stronger relationship to better throwing while poorer performers did not exhibit a pattern – meaning that they did not show a relationship, either positive or negative.

The results of the current study confirm the work of Scibek[31], which discovered a correlation between a forward medicine ball throw and core stability after a six week therapy ball training program with swimmers; however, there was no carryover to test performance or any other sports-specific measures. Current study results are also similar to Nesser et al[28] who discovered at best only a moderate correlation between several sports-specific measures and core stability. One of the tests used was the bench press, which is a similar test to the medicine ball throw because it is a test of upper extremity power and strength. Other sports-specific measures used in the study included a vertical jump, agility shuttle run, and 20- and 40-yard sprints. The purpose of these sports-specific measures is to measure the attributes that are commonly required during many sports (strength, speed, agility, power, etc.) in hopes of predicting performance ability in an actual game or match. There is no way to predict athletic performance in measures such as points per game, assists per game, etc., but the general thought behind sport-specific measures is that the better scores achieved might relate to increased athletic performance (i.e. faster athletes have better athletic performance).

In the current study, the medicine ball throw was performed in a tall-kneeling position and the participants were prohibited from falling forward after the throw which required isometric control of the core muscu-

Table 6. *Test of between-subjects effects, using ANOVA*

Source	Type III Sum of Squares	df	Mean Square	F	Sig
Corrected Model	441.439	1	441.439	2.457	.127
Intercept	85980.263	1	85980.263	478.567	.000
Sex	441.439	1	441.439	2.457	.127
Test order	1003.080	4	250.770	1.479	.235
Age	181.877	1	181.877	1.076	.309
Sport	881.884	4	220.471	1.377	.273

lature. By performing the test in this manner participants were required to stabilize their trunks while performing an explosive upper extremity countermovement. The other tests used did not focus specifically on stabilizing the trunk and allowed for potential compensation from other non-core muscle groups.

According to data from the current study, males scored higher on the test of core stability on average when compared to females. This is consistent with Leetun et al[27] who showed that males have greater core strength compared to females possibly related to bone structure and postural differences in the pelvis. It is possible that core stability may be impacted by the anatomical alignment of the female pelvis which affects the angulation of muscular attachments. Subtle changes in the angle of pull of the core musculature on the pelvis may result in decreased ability to control the trunk. Brophy et al[40] showed that male soccer players have a stronger abdominal strength and thus core control (by their definition) as compared to their female counterparts. Wilson et al[41] likewise demonstrated that males had higher normalized and peak isometric muscle torques of the trunk, hip, knee during a 45 degree single-leg squat than females in all studied muscles groups.

Measuring core stability is a difficult task with no test or measure serving as a gold standard. Double-leg lowering is supported in the literature as a valid and reliable measure of core strength.[33-35] Unfortunately, the function of the core musculature during athletic performance may not be accurately quantified by a stationary, uniplanar test. It seems that it may be more appropriate to use a dynamic measure of core stability which mimics complex, explosive, multiplanar movements. However, at the current time, the literature does not offer a reliable and valid measure that fits these criteria. Functional movements require both mobility and stability within the kinetic chain and would seem to be a reasonable method for comparing core stability and performance because they are dynamic in nature.[42] However, Okada et al[42] showed that at best, only weak relationships are seen between core stability and functional movements and no significant relationship were present to the Functional Movement Screen. This suggests that functional movement screens may be somewhat limited as to their ability to predict athletic performance.

Core stability is a broad construct that includes proprioceptive control, strength, power, and endurance. Tests need to be determined for each of these subcategories because it remains unclear as to which element may be the most important for different sports, as well as which best reflects the combination of tasks related to sport participation. A creation of a gold standard test or test battery would greatly enhance the current knowledge of and the ability to study the relationship between core stability and athletic performance.

Possible limitations in this study include the absence of height and weight measurements for the subjects used in the study. It could be possible that relationships exist between these variables and core stability. The population used in this study may have also impacted the results of the data. A small sample of volunteers with similar demographics and a limited variety of sports were examined. The motivational component of the participants' performance was not measured and may have played a role in test outcomes; some may have been more or less motivated to perform at their greatest ability. The athletes were participants in NAIA-Division II athletics and possibly do not reflect elite athletic performers. The greatest limitation in the study revolves around a lack of a gold standard to measure core stability. The DLL test used in this study measures strength in the sagittal plane but does not measure muscle endurance, proprioception, or other key multiplanar musculature thought to control the core. Future researchers should attempt to include larger samples, a greater variety of sports (as there may be other activities that require greater core control), elite athletes, and a more demographically diverse sample.

CONCLUSION

The results of this pilot study suggest that a significant, although fair or weak relationship exists between the double leg lowering test as a measure of core stability and the medicine ball throw. Top performers demonstrated a stronger, significant correlation between these tests as compared to bottom performers. The data demonstrated that males, on average, scored better on the test of core stability as compared to females. These results provide the basis for future research, but do not provide answers to many of the unknown questions concerning the relationship between core stability and athletic performance. Future researchers should seek to identify a gold standard test or battery of tests that quantifies core stability as it pertains to athletic performance. Also, the specific functions of the core, such as stability, strength, or endurance, should be examined separately to determine the relative importance of each. Additional research should focus on specific sports and actual sports performance outcomes such as points per game, goals scored, etc. but also include maximal performances ideally linked to the activity of choice (i.e.-ball speed or distance if related to throwing). It also would be beneficial to examine the relationship between core stability and additional athletic performance tests. The body of literature concerning athletic performance and core stability continues to evolve, but many essential questions remain unanswered. Until the relationship between core stability and athletic performance can be scientifically demonstrated the in the evidence, it will remain hypothetical and theoretical in nature.

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